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[54] **PLANAR FLAT PLATE SCANNING ANTENNA**

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[51] **Int. Cl.**[7] **H01Q 13/10**

[52] **U.S. Cl.** .... **343/771**; 343/700 MS; 343/753; 343/909

[58] **Field of Search** .... 343/700 MS, 753, 343/754, 757, 767, 770, 771, 781 P, 785, 850, 853, 909, 911 R, 911 L

[56] **References Cited**

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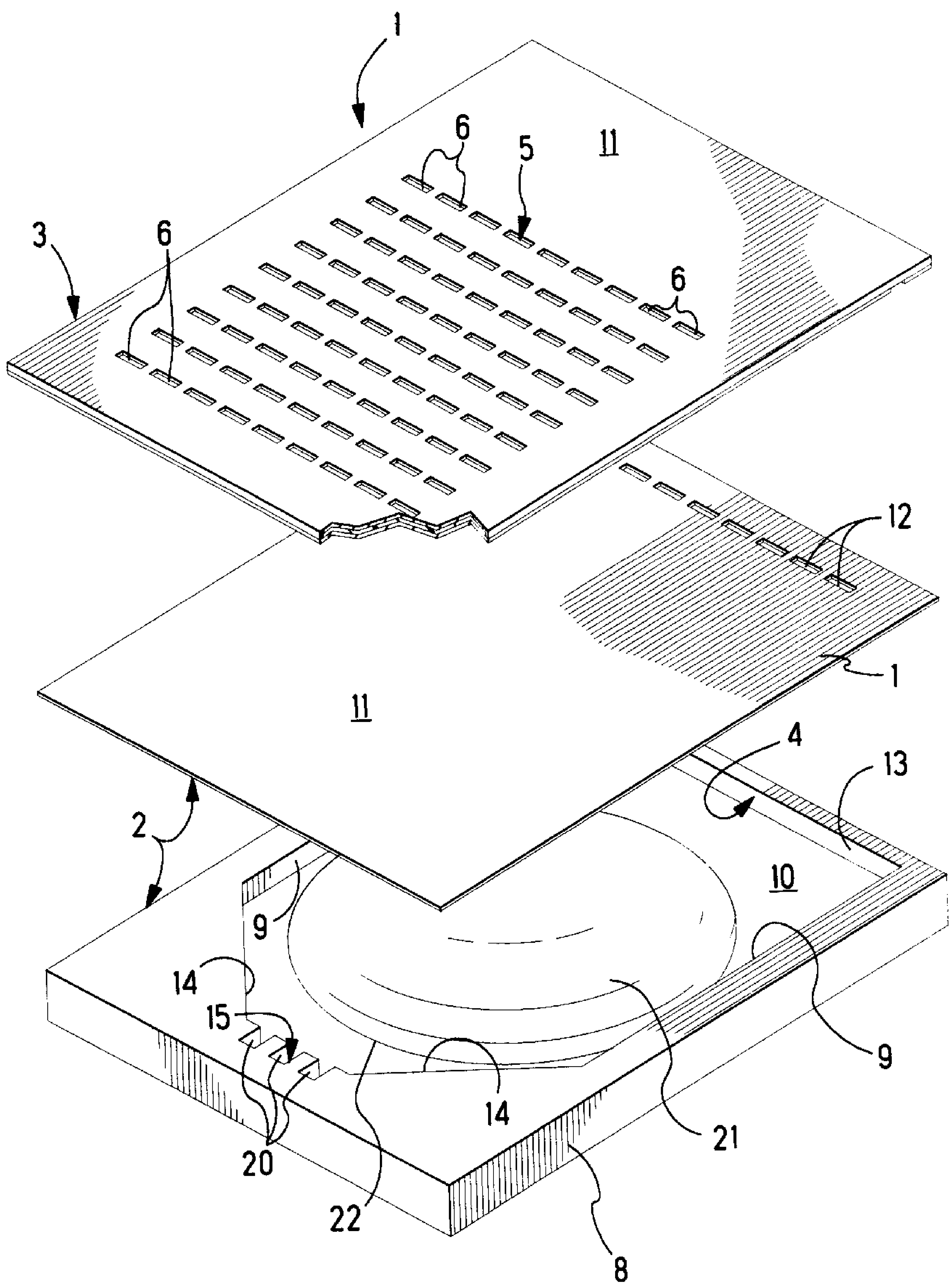
Assistant Examiner—Tho Phan

[57] **ABSTRACT**

A scanning antenna (**1**) has, a first waveguide (**2**) with parallel metal plates (**10, 11**), a waveguide feed (**19**) substantially at a focus (**15**) of the first waveguide (**2**), the plates (**10, 11**) being partially filled therebetween with a biconvex dielectric body (**21**) emanating a wave of planar phase front, and a planar waveguide bend (**4**) having a planar profile (**13**) redirecting an incident wave of planar phase front for propagation in a second waveguide (**3**) having an array of radiating antenna elements (**5**).

14 Claims, 5 Drawing Sheets



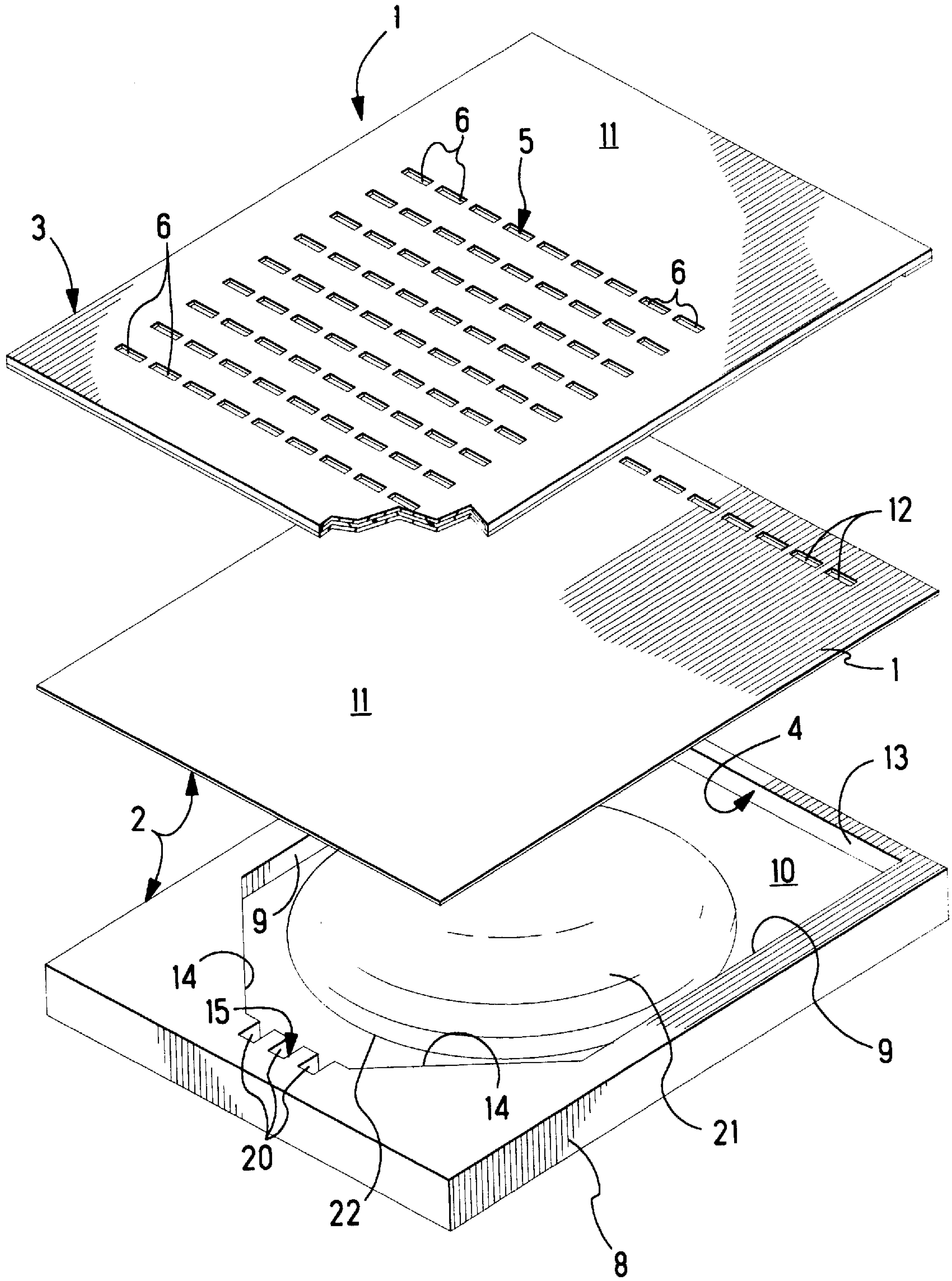


Fig. 1

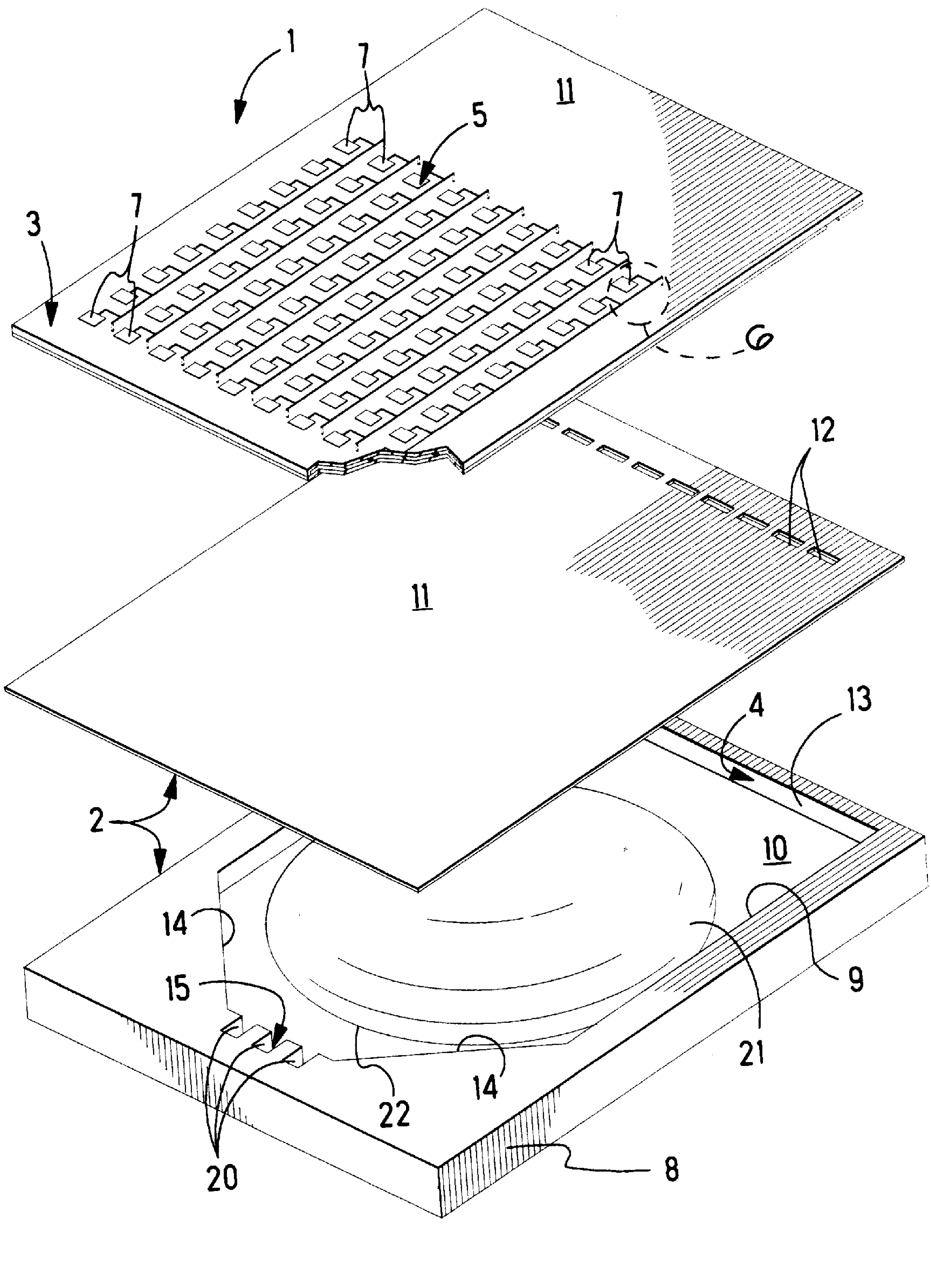


Fig. 2

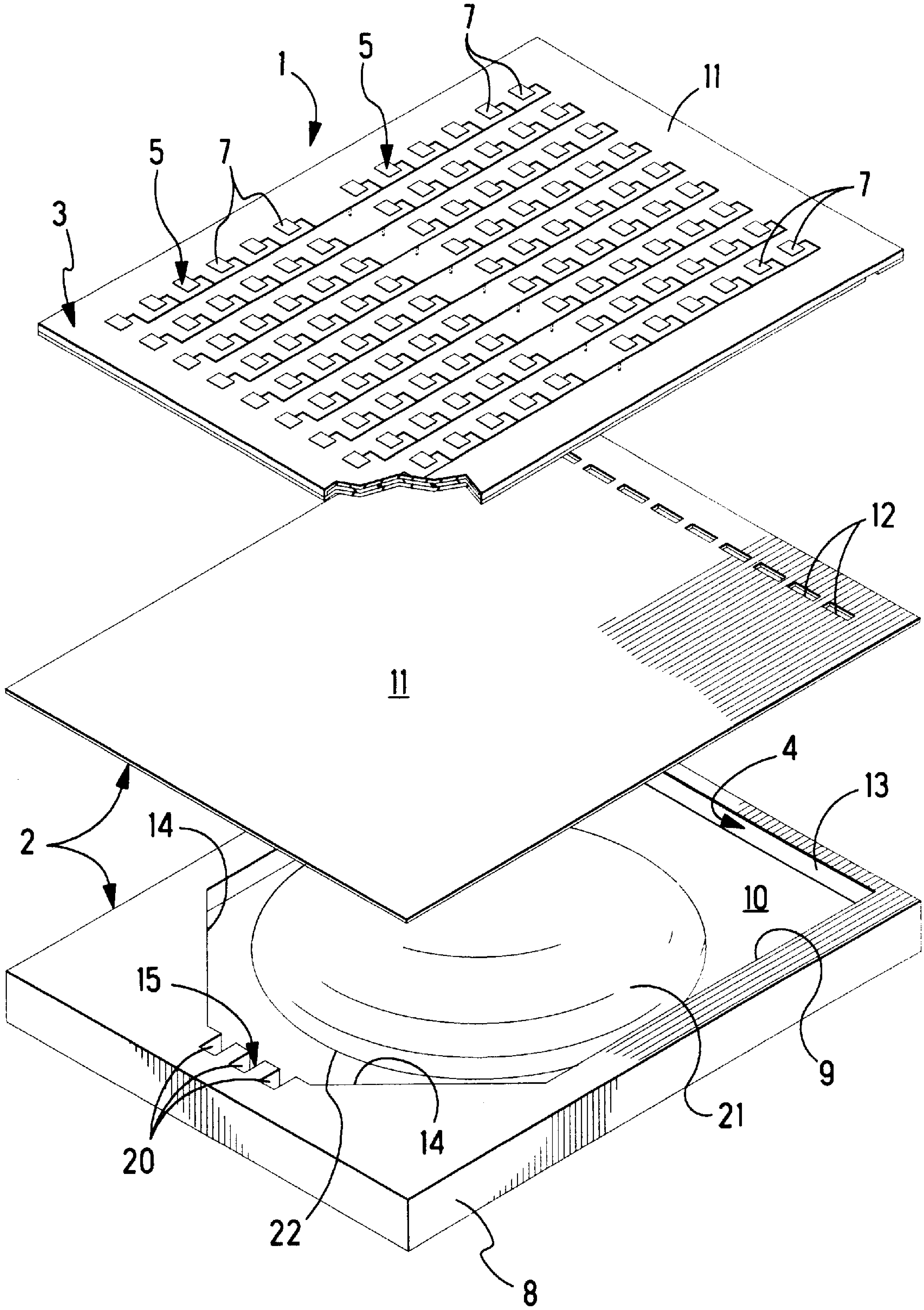


Fig. 3

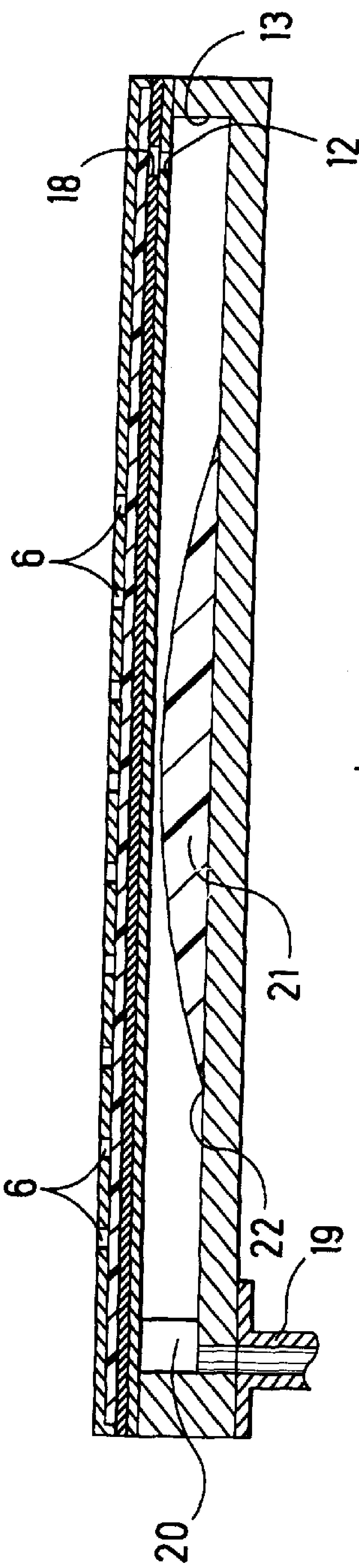


Fig. 4

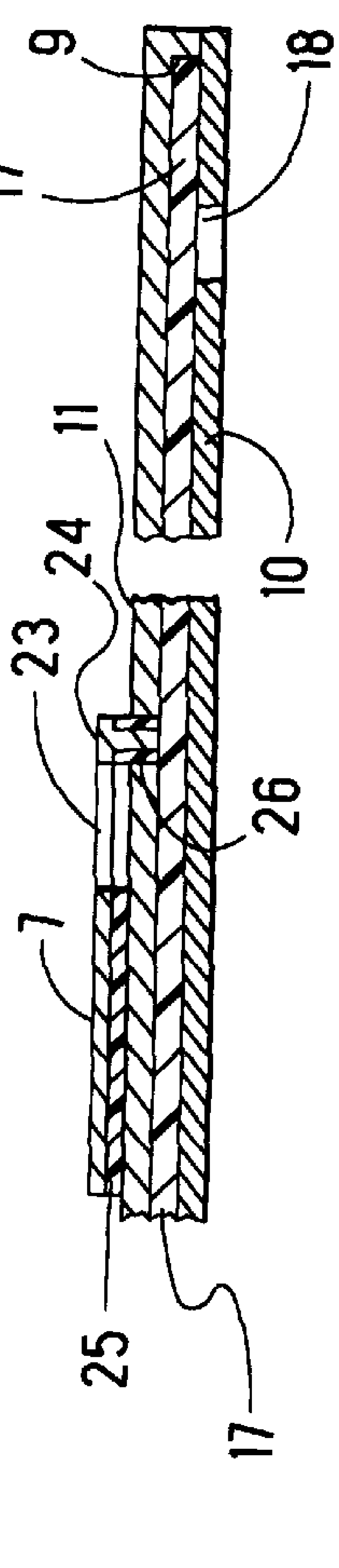


Fig. 5

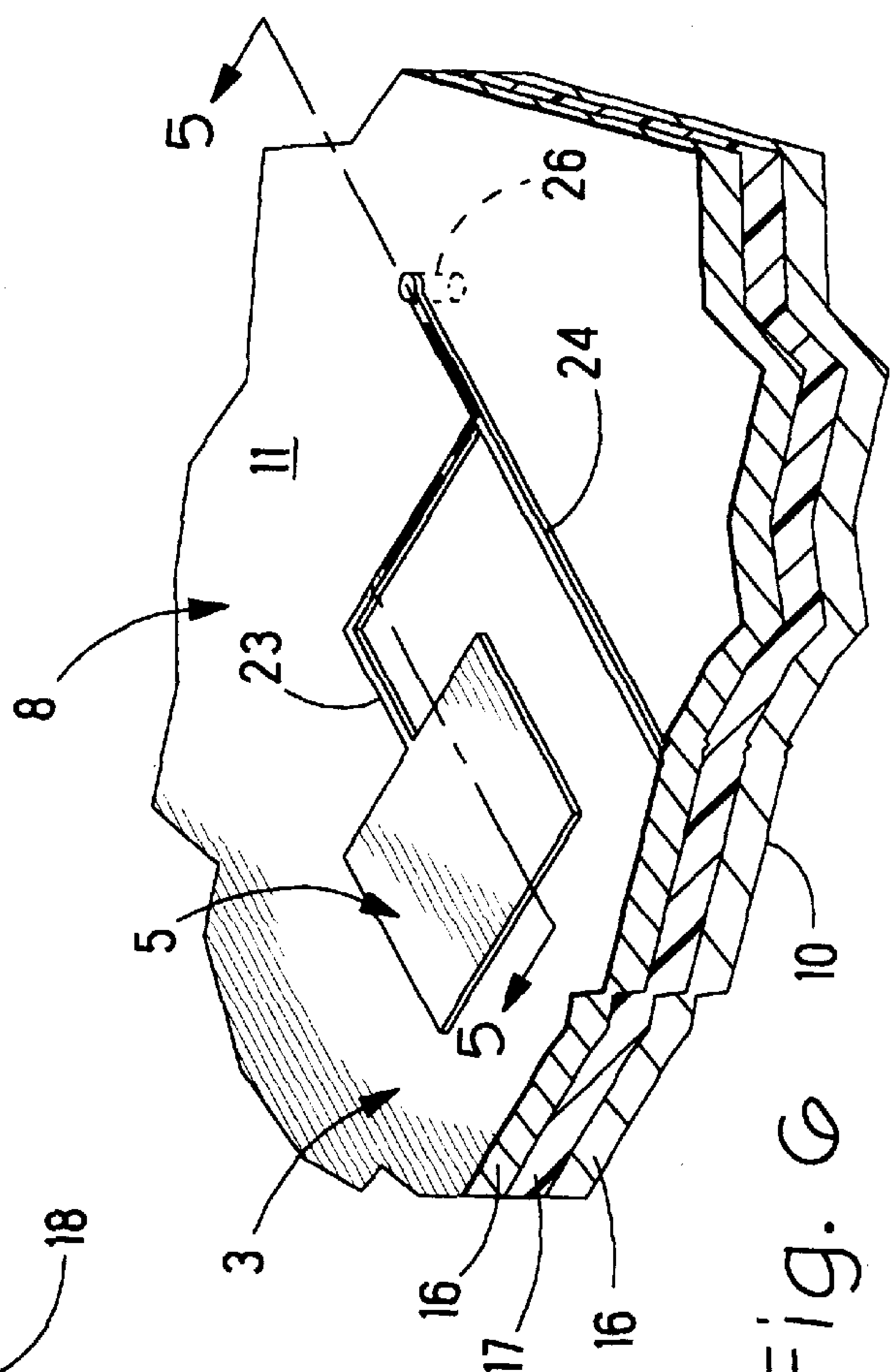


Fig. 6

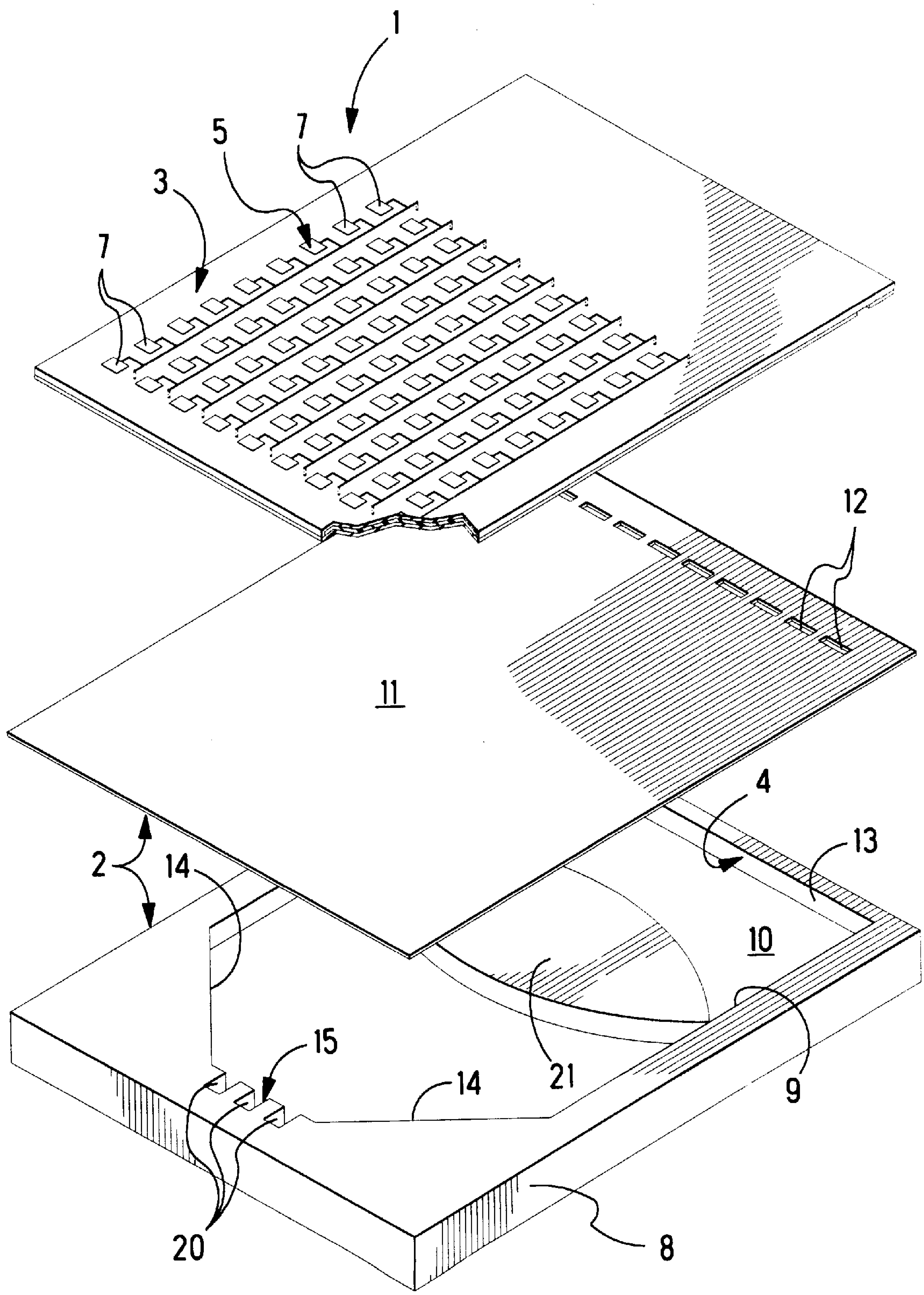


Fig. 7

PLANAR FLAT PLATE SCANNING ANTENNA

BACKGROUND OF THE INVENTION

A known scanning antenna is disclosed in PCT Application Number WO 91/17586 having first and second, flat plate waveguides connected by a waveguide bend. Waveforms at a focus of the first waveguide propagate as a beam of plane waves having a nonplanar, thin cylindrical, phase front, and become redirected by a parabolic profile of the waveguide bend to a beam for propagation in the second waveguide having an array of antenna apertures to be illuminated by the redirected beam.

In the known antenna, the waveguide bend has a parabolic profile that redirects the nonplanar phase front in reverse, by a 2π change in phase, to propagate in the second waveguide. The parabolic profile of the waveguide bend has a detrimental effect on the redirected phase front. A parabolic profile must be selected so as to provide a redirected beam pattern that may vary from, a narrow beam pattern with low side lobes, characteristic of a deep parabolic profile, to a broader beam pattern of more uniform illumination of the array of antenna elements with higher scattering, characteristic of a shallow parabolic profile. Accordingly, attainment of a redirected beam with a planar phase front is difficult to attain by a waveguide bend with a parabolic profile redirecting a beam having an nonplanar phase front.

In the known antenna, the first waveguide has parallel metal plates filled therebetween with dielectric material. The dielectric material extends from the focus of the waveguide to the parabolic waveguide bend. The dielectric material is without a desired feature that would emanate a planar phase front toward the waveguide bend. A wave of planar phase front would simplify the waveguide bend to a planar profile, and would reduce the detrimental effect of a parabolic waveguide bend on the redirected phase front.

SUMMARY OF THE INVENTION

According to the invention, the first waveguide has a waveguide feed substantially at a focus of the first waveguide, the focus being the focus of a biconvex dielectric body partially filling between parallel metal plates of the waveguide and emanating a wave of planar phase front incident on a planar waveguide bend having a planar profile directly opposite the dielectric body from the focus, the planar profile redirecting an incident wave of planar phase front for propagation in a second waveguide superposed with the first waveguide.

The planar profile reduces a need to focus a redirected beam of planar phase front, and reduces beam scattering due to off-axis propagation of a redirected phase front.

Embodiments of the invention will now be described by way of example with reference to the drawings, according to which:

FIG. **1** is an isometric view of a scanning antenna with parts separated from one another;

FIG. **2** is an isometric view of another embodiment of a scanning antenna with parts separated from one another;

FIG. **3** is an isometric view of another embodiment of a scanning antenna with parts separated from one another;

FIG. **4** is an enlarged section view of the scanning antenna as shown in FIG. **1**, and with the parts assembled;

FIG. **5** is an enlarged section view taken along the line **5**—**5** of FIG. **6**;

FIG. **6** is an enlarged fragmentary view of a portion of the scanning antenna as shown in FIG. **1**; and

FIG. **7** is an isometric view of another embodiment of a scanning antenna.

DESCRIPTION

With reference to each of FIGS. **1**, **2**, **3** and **7**, a scanning antenna **1** suitable for mm-wave, millimeter-wave, 77 gHz., for example, has a flat plate, first waveguide **2** and a flat plate, second waveguide **3** connected by a waveguide bend **4**. In the first waveguide **2**, a wave form propagates from a focus **15** of the first waveguide **2**, and becomes redirected by the profile **13** of the waveguide bend **4** for propagation in the second waveguide **3** having an array of antenna elements **5** in the form of apertures **6**, FIG. **1**, or, alternatively, antenna patch elements **7**, FIGS. **2**, **3** and **7**.

With reference to each of FIGS. **1**, **2**, **3** and **7**, the first waveguide **2** is fabricated with a suggested construction as a metal conducting body **8** providing side walls **9** unitary with a conducting base plate **10**, together defining a cavity for mm-wave propagation. The side walls **9** are magnetically lossy material absorbing misdirected, mm-waves. A conducting top plate **11** covers the cavity, and registers on the side walls **9**. The top plate **11** has a single row of apertures **12** for the waveguide bend **4**. The side walls **9** meet the reflecting profile **13** of the waveguide bend **4** at an end of the first waveguide **2**. The side walls **9** meet respective walls **14** that taper to a focus **15** of the first waveguide **2**.

With reference to FIG. **6**, the second waveguide **3** has copper cladding **16** surrounding a sheet of dielectric material **17** such as polytetrafluoroethylene. The copper cladding **16** forms the conducting body **8**, similar to the conducting body **8** of the first waveguide **2**, with a base plate **10** and a parallel top plate **11**. The dielectric material **17** fills between the base plate **10** and the top plate **11**, and serves as the propagation medium. An exemplary antenna element **5** is shown in FIG. **6**. As shown in FIGS. **4** and **5**, a waveguide opening **18** through the base plate **10** is aligned with the apertures **12** of the waveguide bend **4**.

With reference to FIG. **4**, a waveguide feed **19** is substantially at the focus **15** of the first waveguide **2**. For example, the waveguide feed **1** comprises at least one waveguide duct **20**, FIGS. **1**, **2**, **3** and **7**, or multiple waveguide ducts **20** substantially at the focus **15**, for example, feeding a wave in opposite, transmitting and receiving directions, depending upon which duct **20** is connected to a transmitter portion or receiver portion of a known electronic transceiver apparatus, not shown. The direction of propagation applies in reference to a transmit mode, when a wave propagates from the focus **15**. The direction of propagation further applies in reference to a receive mode, when a wave propagates toward the focus **15**.

With reference to FIGS. **1**, **3** and **7**, a biconvex dielectric body **21** will now be described. The biconvex dielectric body **21** is spaced from the focus **15** and from the waveguide bend **4**, and, thereby, partially fills between the metal plates **10** and **11** of the first waveguide **2**. The remaining area between the plates **10** and **11** is filled with air as a dielectric medium of propagation.

The dielectric body **21** is biconvex in the direction of propagation, serves as a mm-wave lens, and has, as its lens focus **15**, the focus **15** of the first waveguide **2**. Because the first waveguide **2** is very thin, a wave propagating from the focus **15** toward the dielectric body **21** will have a nonplanar, thin cylindrical, phase front, and will be incident on the dielectric body **21**. The dielectric body **21** is biconvex in the direction of propagation to emanate the wave with a planar phase front propagating toward the waveguide bend **4**. An incident wave of planar phase front simplifies the shape of the waveguide bend **4** to a planar profile **13**.

The planar phase front becomes redirected by the planar profile **13** of the waveguide bend **4** for propagation, in reverse, in the second waveguide **3** as a beam of planar phase front. Due to the planar profile **13**, the redirected beam of planar phase front is focused at infinity, which avoids a need to focus the redirected beam to reduce scattering by off-axis propagation of redirected phase fronts. The planar phase front provides uniform illumination of the array of antenna elements **5**, with reduced scattering loss due to the beam spreading laterally.

The planar profile **13** of the waveguide bend **4** reduces the detrimental effect of a known parabolic waveguide bend **4** on the redirected phase front. A parabolic profile must be selected so as to provide a redirected beam pattern that varies from, a narrow beam pattern with low side lobes, characteristic of a deep parabolic profile, to a broader beam pattern of more uniform illumination of the array of antenna elements **5** with higher scattering, characteristic of a shallow parabolic profile. Accordingly, a redirected beam with a planar phase front, and with minimum skattering, is difficult to attain with a parabolic profile being used to redirect a beam having a nonplanar phase front.

According to one embodiment, in FIG. **7**, the dielectric body **21** is of uniform thickness, transverse to the direction of propagation, and of uniform dielectric constant, and is biconvex in the direction of propagation. The thickness bridges between the parallel plates **10** and **11** that have a plate spacing sufficiently small for propagation of a wave of TEM mode. Propagation of a wave in the dielectric body **21** can be modeled by an analysis of an optical wave propogating through an optically transmitting biconvex lens.

According to another embodiment, in each of FIGS. **1**, **2** and **3**, the dielectric body **21** is of uniform dielectric constant and is cylindrical about an axis transverse to the direction of propagation, with a thickness progressively increasing concentrically from a minimum thickness at a cylindrical edge **22**.

The effective index of refraction for this mode is expressed as:

$$\tan[k_1(s-t)]+k_2/\epsilon_r[\tan(k_2t)]=0$$

where

$$k_1=2\pi/\lambda(1-n^2)^{1/2},\ k_2=2\pi/\lambda(\epsilon_r-n^2)^{1/2}$$

s is the spacing between the plates

t is the thickness

ϵ_r is the dielectric constant of the body

λ is the free space wavelength

A slight deformation from parallelism of the interface between air and the dielectric body **21** has an insignificant effect on the velocity of the wave at any point when the thickness varies, so that a known Luneberg relation is satisfied, according to the equation:

$$n^2=2-(r/R)^2$$

where:

n=dielectric constant

r=radial distance from center axis

R=radius of waveguide at the center of the waveguide, r=0, and n=2, its maximum value. When r=R, n=1.

With reference to FIG. **6**, the antenna patch elements **7** are unitary with respective, conducting, secondary feed lines **23** linked to a unitary primary feed line **24**. As shown in FIG. **4**, the patch elements **7** and the secondary feed lines **23** and each primary feed line **24** are fabricated, for example, as a pattern of plated metal adhered to dielectric material **25**, in turn, adhered to the top plate **11**. The plated metal extends through an opening in the top plate **11**, and is encircled by the dielectric material in the opening to provide a coaxial feed **26**. Further details of the patch elements **7** and their construction are described in U.S. Pat. No. 5,712,644, incorporated herein by reference.

In summary, a scanning antenna has first and second, flat plate waveguides **2** and **3** connected by a waveguide bend **4**. Wave forms at a focus **15** of the first waveguide **2** propagate with a nonplanar phase front, and emanate with a planar phase front from a biconvex dielectric body **21** toward the profile **13** of the waveguide bend **4** for propagation in the second waveguide **3** having an array of radiating antenna elements **5**.

The first waveguide **2** has parallel metal plates, a waveguide feed **19** substantially at a focus **15** of the waveguide, the plates being partially filled therebetween with a biconvex dielectric body **21** emanating a wave of planar phase front, and a planar waveguide bend **4** having a planar profile **13** directly opposite the dielectric body **21** from the focus **15**, the planar profile **13** redirecting an incident wave of planar phase front for propagation in a second waveguide **3** superposed with the first waveguide **2**.

Other embodiments and modifications of the invention are intended to be covered by the spirit and cope of the appended claims.

What is claimed is:

1. A scanning antenna comprising: a first waveguide having parallel metal plates, a waveguide feed substantially at a focus of the first waveguide, the plates being partially filled therebetween with a biconvex dielectric body emanating a wave of planar phase front, and a planar waveguide bend having a planar profile directly opposite the dielectric body from the focus, the planar profile redirecting an incident wave of planar phase front for propagation in a second waveguide superposed with the first waveguide, and the second waveguide having an array of radiating antenna elements.

2. A scanning antenna as recited in claim **1** wherein, the radiating antenna elements are antenna patch elements connected by secondary feed lines to a primary feed line, and a coaxial feed through a conducting top plate of the second waveguide.

3. A scanning antenna as recited in claim **1** wherein, the radiating antenna elements are apertures in a phased array.

4. A scanning antenna as recited in claim **1** wherein,

the dielectric body is biconvex in the direction of propagation for either a transmit mode or a receive mode.

5. A scanning antenna as recited in claim **1** wherein,

the dielectric body has a progressively increasing thickness from a minimum at a cylindrical circumference to a maximum along an axis transverse to a direction of propagation.

6. A scanning antenna as recited in claim **1** wherein,

the biconvex dielectric body has a constant thickness and a uniform dielectric constant.

7. A waveguide as recited in claim **6** wherein, the dielectric body is biconvex in the direction of propagation for either a transmit mode or a receive mode.

8. A waveguide as recited in claim **6** wherein, the dielectric body has a progressively increasing thickness from a minimum at a cylindrical circumference to a maximum along an axis transverse to a direction of propagation.

9. A waveguide as recited in claim **6** wherein, the biconvex dielectric body has a constant thickness and a uniform dielectric constant.

10. A waveguide of a scanning antenna comprising:

a waveguide feed substantially at a focus of a biconvex dielectric body partially filling between parallel metal plates, the dielectric body emanating a wave of planar phase front incident on a planar waveguide bend having a planar profile directly opposite the dielectric body from the focus, the planar profile redirecting an incident wave of planar phase front for propagation in another waveguide having antenna radiating elements.

11. A scanning antenna comprising: first and second, flat plate waveguides connected by a waveguide bend, a focus of the first waveguide propagating a wave having a nonplanar phase front toward a biconvex dielectric body, the body emanating the wave with a planar phase front toward a planar profile of a waveguide bend for propagation in the second waveguide having an array of radiating antenna elements.

12. A scanning antenna as recited in claim **11** wherein,

the dielectric body is biconvex in the direction of propagation for either a transmit mode or a receive mode.

13. A scanning antenna as recited in claim **11** wherein,

the dielectric body has a progressively increasing thickness from a minimum at a cylindrical circumference to a maximum along an axis transverse to a direction of propagation.

14. A scanning antenna was recited in claim **11** wherein, the biconvex dielectric body has a constant thickness and a uniform dielectric constant.

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